

William Malcolm Bauer

FEEDBACK IN TRANSISTOR AMPLIFIERS.

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in
TRANSISTOR AMPLIFIERS

-BY-

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Amplifiers
FEEDBACK IN TRANSISTOR CIRCUITS

by

W. M. BAUER

As with tube circuits, feedback is of importance in controlling the gain, the input and the output impedance of an amplifier. Also, it has the stabilizing effect to make gain more independent of frequency, bias voltage changes, changes of operating point, and changes of parameters with temperature or replacement of a transistor. Non-linearity distortion is also reduced by negative feedback. Feedback is more necessary for transistors than for tubes. The reasons are that transistors are affected by temperature, and the degree of uniformity of transistors of a given type is less than for tubes. The amplification factor of a tube is not much affected by bias, but the current transfer ratio of a transistor is considerably affected by the location of the operating point. However a fairer basis of comparison is with the transconductance of a tube. Even a sharp cut-off pentode has a large variation in g_m with shift of the operating point. This variation may even be greater than the change of β of a transistor. At $V_{CE} = -3$ v and $I_E = -0.2$ ma., $\beta = 32$ for a 2N104 transistor. At $V_{CE} = -6$ v and $I_E = -1.0$ ma., $\beta = 44$. Another reason that feedback is more important for transistors is that the input resistance of a transistor is of more concern. In many circuits, the low input resistance of a transistor as compared with a tube is decidedly a handicap, and feedback is a necessity to provide an input resistance approaching that of a tube. Furthermore,

change of the input resistance of a transistor has a marked effect on the gain of the preceding stage, or upon the mismatch loss with respect to the available power from a signal source.

EMITTER DEGENERATION

The chapter on biasing showed that the bias circuit of a transistor generally includes a resistance between the emitter and ground in the common emitter circuit. If this resistor is unbypassed, it provides AC negative feedback in addition to the DC negative feedback which tends to stabilize the operating point. The action is identical with that of the cathode resistor of the tube circuit, which furnishes both DC and AC cathode degeneration. It is interesting to note that the cathode resistor is as far as a tube circuit goes in providing stabilization for the Q-point.

The circuit diagram of figure 1 shows a transistor amplifier which has a resistor R_E inserted in the emitter lead of a grounded emitter circuit. Figure 2 shows the AC equivalent circuit in which the internal negative feedback of the transistor is neglected. This is a good approximation for load resistance less than about 10 k. The transistor AC input resistance between emitter and base is approximately r_{ib} with respect to emitter current. From the circuit, it is apparent that a fair approximation to the voltage gain in the presence of emitter degeneration is

$$\frac{E_o}{E_{in}} = A_v' = \frac{\alpha \cdot R_L}{R_E + r_{ib}} \quad (1)$$

Thus voltage gain may be reduced at will by increase of R_E . As a check,

note that if $R_E = 0$, the equation becomes equation 3, p. 3 of the simple chapter. We remember that the voltage gain of the common base and common emitter circuits is identical. If a desired value of gain is to be obtained, equation 1 may be solved for R_E .

$$R_E = \frac{\alpha \cdot R_L}{A'_V} - r_{ib} \quad (2)$$

The input resistance will be very nearly that of the common collector circuit (simple treatment p. 9) where R_E substitutes for R_L . Figure 3 shows the input resistance to be that of the transistor as seen by the base current, augmented by the current multiplication of the emitter resistor.

$$\begin{aligned} R_{i1}' &= R_{ie} + R_E(A_{ie} + 1) \\ R_{i1}' &= r_{ie} + R_E(\beta + 1) \doteq \beta R_E \end{aligned} \quad (3)$$

Neglecting internal feedback, the current gain with and without emitter degeneration will be substantially the same.

$$A_i' \doteq A_i \quad (4)$$

The effect of emitter degeneration on output impedance will now be derived starting with figure 4. The AC circuit is shown with a signal being applied to the collector. Figure 5 replaces the transistor by its h-parameter common emitter equivalent circuit, with internal feedback neglected. Figure 6 has a Thevenin equivalent replacement for the Norton portion of figure 5. It is clear that the signal generator sees

$$\begin{aligned} R_2' &= r_{22e} + \frac{\beta R_E r_{22e}}{R_E + R_s + r_{ie}} + \frac{R_E(R_s + r_{ie})}{R_E + R_s + r_{ie}} \\ R_2' &= r_{22e} \left[\frac{R_E(\beta + 1) + R_s + r_{ie}}{R_E + R_s + r_{ie}} \right] \end{aligned} \quad (5)$$

It is seen that emitter degeneration, like cathode degeneration, increases output impedance.

EXACT TREATMENT OF EMITTER DEGENERATION

The experimental method of determining the influence of the emitter resistor would be to connect it to the emitter, and measure the parameters of the combination of the transistor and the resistor. Figure 7 shows a stage with emitter resistor R_E . Figure 8 shows the combination of the transistor and R_E , for which the parameters are β' , r_i' , r_{11}' , r_o' , and r_{22}' . Let us perform the experiment analytically as follows. The AC open circuited input resistance is clearly the sum of the transistor input resistance and the resistor.

$$r_{11}' = r_{11} + R_E \quad (6)$$

The output resistance when the input is AC open, is

$$r_{22}' = r_{22} + R_E \quad (7)$$

Figure 9 shows the circuit for measuring r_i' . It is apparent that r_i' is the input resistance of a common collector circuit having a load R_E . This is given in equation 49, p. 16 of chapter 2.

$$r_i' = r_{ic} \cdot \frac{1 + \frac{R_E}{r_{oc}}}{1 + \frac{R_E}{r_{22c}}} \quad (8)$$

The conversion table of p. 22, chapter 2, will give

$$r_i' = r_i \cdot \frac{1 + \frac{R_E(\beta + 1)}{r_i}}{1 + \frac{R_E}{r_{22}}} \quad (9)$$

where r_i and r_{22} are common emitter values.

Figures 10 and 11 show the circuit when r_o' is being measured. From figure 11 it is clear that we are really measuring the output resistance of a transistor in the common base configuration in which there is a source resistance R_E . Equation 51, p. 16, chapter 2, gives

$$r_o' = r_{22b} \cdot \frac{1 + \frac{r_{ib}}{R_E}}{1 + \frac{r_{11b}}{R_E}} \quad (10)$$

By use of the conversion table, this becomes

$$r_o' = r_{22} \left[\frac{(\beta + 1) R_E + r_i}{R_E + r_{11}} \right] = \quad (11)$$

where r_{22} , r_i , and r_{11} are common emitter values.

Figure 12 shows the circuit when we are measuring β' . We have the circuit of an emitter follower having R_E as the load. Our problem is to find the current gain of the common collector circuit, with this difference, that now we want $\frac{i_c}{i_b}$ instead of $\frac{i_e}{i_b}$. By equation 48, p. 16 of chapter 2,

$$\frac{i_e}{i_b} = \frac{\beta + 1}{1 + \frac{R_E}{r_{22c}}} \quad (12)$$

$$\text{Now} \quad i_c = i_e - i_b \quad (13)$$

$$\text{or} \quad \frac{i_c}{i_b} = \frac{i_e}{i_b} - 1 \quad (14)$$

$$\text{so} \quad \beta' = \frac{i_c}{i_b} = \frac{\beta + 1 - 1 - \frac{R_E}{r_{22c}}}{1 + \frac{R_E}{r_{22c}}} \quad (15)$$

$$\beta' = \frac{\beta - \frac{R_E}{r_{22}}}{1 + \frac{R_E}{r_{22}}} \quad (16)$$

where r_{22} is the common emitter value.

Equations 6, 7, 9, 11 and 16 are the new set of parameters applying to the combination of a transistor with a common emitter resistor R_E . The performance of the circuit of figure 7 is computed in the usual manner using these new parameters in equations 48 - 52, p. 16 of chapter 2. Unless the AC load resistance is greater than 10 k, the results of equations 1, 3 and 5 give all the accuracy that is wanted.

COMMON COLLECTOR AMPLIFIER

The voltage gain of the common collector circuit is given by equation 21, p. 8 of the simple treatment with sufficient accuracy for any value of R_L .

$$A_v = \frac{R_L}{R_L + r_{ib}} \quad (17)$$

It is simpler than the exact equation 50, p. 16. The input resistance is like equation 3.

$$R_i = R_{ie} + R_L A_{ic}$$

$$R_i \approx \beta R_L \quad (18)$$

Figures 13 and 14 show the determination of output resistance. The base loop gives

$$i_b = \frac{v}{R_s + r_{ie}} \quad (19)$$

Figure 14 shows

$$i_e = i_b + \beta i_b + \frac{v}{r_{22e}} \quad (20)$$

$$= \frac{(\beta + 1) v}{R_s + r_{ie}} + \frac{v}{r_{22e}} \quad (21)$$

So

$$R_2 = \frac{r_{22e} (R_s + r_{ie})}{(\beta + 1)r_{22e} + R_s + r_{ie}} \quad (22)$$

AC FEEDBACK TYPES

As we have seen, feedback may occur for DC as well as AC. For a bypassed emitter resistor, there is only DC feedback. Feedback is negative if the net input signal is less than that from the signal source. Feedback is either of series or shunt type. Series means that the return or feedback voltage is in series with the signal voltage. The cathode follower and emitter follower circuits are illustrations of series negative AC voltage feedback. The entire output voltage opposes the signal voltage. Shunt feedback describes the type of feedback circuit which draws current from the signal source and, by virtue of the internal impedance of the source, decreases the signal voltage reaching the amplifier. A two-stage tube amplifier having a feedback path between plates is of this shunt type. Another illustration is the Miller type of feedback as used in operational amplifiers where the feedback path is from plate to grid. The self bias transistor circuit in which base bias current is supplied from the collector is like the Miller feedback. Shunt feedback is most effective if the source is an approximation to a constant current source, for then the entire feedback current must flow

through the amplifier input resistance. Shunt feedback would be ineffective if the signal source were a constant voltage one. Transistor output impedances are high as compared with input impedances, thus the driving source may in many cases appear nearly as ^aconstant current source. High impedance transducers also appear as nearly constant current sources for transistor input resistances. As a transistor must usually be current driven rather than voltage driven to avoid non-linear distortion, its signal source must be tending toward the constant current type. Another way of saying it is that the source should have high internal resistance as compared with the non-linear input resistance of a transistor. In this way the non-linear resistance is swamped by the linear resistance. This is why the dynamic transfer characteristic curve of a tube is straighter than its static characteristic. If a signal source has a resistance comparable to the amplifier input resistance, it cannot be regarded as constant voltage or constant current and a circuit solution is necessary. This solution could result in two Thevenin voltages in series, or two constant current generators feeding the parallel resistances of generator and amplifier.

Feedback is further described by the derivation of the feedback. A series feedback voltage may be derived either proportional to the output voltage or proportional to the output current. The emitter follower would be described as having 100% AC negative series voltage feedback. The amplifier with emitter degeneration is described as having AC negative series current feedback. In shunt type feedback, the current which is fed back may be proportional to either the voltage or current in the output load. The self-bias transistor circuit has AC negative shunt voltage feedback.

THE EFFECTS OF AC NEGATIVE FEEDBACK

1. Gain is reduced. Series feedback reduces the net input voltage. Shunt feedback reduces the net input current. As the transistor is fundamentally a current amplifier, then the output current is reduced.

2. Input resistance.

a. Series feedback increases input resistance. The opposing return voltage decreases the input current which makes the apparent load resistance greater for the signal source.

b. Shunt feedback decreases input resistance. The feedback path in effect shunts the signal source with a resistance paralleling the amplifier and thereby lowers the apparent resistance which loads the signal source.

3. Output resistance. If we draw more current from an amplifier, its output voltage decreases. This is expressed by saying the amplifier has an AC output impedance which is a Thevenin or Norton equivalent internal resistance. If the increment of load current causes an increment of feedback, the input to the amplifier decreases. This results in only a slight increment of load current when a large reduction of load resistance is made, since the output voltage drops a lot. The amplifier looks almost like a constant current generator. Thus if feedback is of the current type, proportional to load current, then output resistance is increased by feedback. Emitter degeneration is an example. However, if the increment of load current, obtained by reduction of load resistance, causes a decrease of feedback, then the input to the amplifier increases. This results in only a small decrease of output voltage

for a large increment of output current. The amplifier looks almost like a constant voltage generator. Thus if feedback is of the voltage type, proportional to load voltage, then output resistance is decreased by feedback. The emitter follower is an example.

4. Effect on previous stage. The change of input impedance of the stage having feedback causes a considerable change of the voltage gain of the preceding stage, and some change of its current gain. Furthermore, with RC coupling, the fraction of the transistor output current that is useful to drive the stage having feedback is affected. If the input resistance is increased by series feedback, then the useful fraction of output current of the preceding stage is reduced.

AC SERIES NEGATIVE CURRENT FEEDBACK

Emitter degeneration is a single stage example which has already been considered, and the voltage gain obtained in equation 1 and also by the h-parameter method. The object here is to treat the problem from the viewpoint of negative feedback. Figure 15 shows the signal voltage and the feedback voltage in series opposition. The fraction of the output voltage which is fed back will be designated by F instead of the usual symbol β to avoid confusion with the short circuit current transfer ratio of the transistor.

$$E_1 = E_{in} + F \cdot E_o$$

where E_o is negative

$$A_v' = \frac{E_o}{E_{in}} = \frac{E_o}{E_1 - F \cdot E_o} = \frac{E_o/E_1}{1 - F \left(\frac{E_o}{E_1} \right)} = \frac{A_v}{1 - F A_v} \quad (23)$$

This is the well-known feedback equation in which A_v is negative in

sign for negative feedback. By figure 15,

$$F = \frac{I_e \cdot R_E}{I_c \cdot R_L} = \frac{R_E}{\alpha \cdot R_L} \quad (24)$$

The general current feedback circuit is shown in figure 16. Figure 17a determines the Thevenin equivalent circuit shown in 17b. Figure 18 shows the input circuit with the feedback circuit replaced by the equivalent circuit of figure 17b. It is apparent that the input resistance is

$$R_1' = R_1 + R_F(A_1 + 1) \quad (25)$$

This agrees with equation 3 for the particular case of emitter degeneration. Now by figure 16,

$$E_O = A_V' \cdot E_{in} = A_V E_1 \quad (26)$$

so

$$A_V' = A_V \frac{E_1}{E_{in}} = A_V \frac{R_1}{R_1'} \quad (27)$$

Returning to equation 25

$$R_1' = R_1 \left(1 + \frac{R_F \cdot A_1 \cdot R_L}{R_1 \cdot R_L} + \frac{R_F}{R_1} \right)$$

and since $\frac{A_1 \cdot R_L}{R_1} = A_V$;

and $F_O = \frac{R_F}{R_L}$

$$R_1' = R_1 \left(1 + F_O A_V + \frac{R_F}{R_1} \right) \quad (28)$$

Thus by 27,

$$A_V' = \frac{A_V}{1 + F_O A_V + \frac{R_F}{R_1}} \quad (29)$$

F_o is the voltage feedback fraction when the R_L is infinite, in which case equation 29 reverts to the more usual form of equation 23. $F_o \cdot A_v \cdot E_L$ is the component of the feedback voltage due to the load current, and $(R_F/R_L) E_L$ is that due to the input current flowing through R_F .

Output impedance may be determined from consideration of figure 16. Suppose R_L is decreased, the result is a decrease in E_o and an increase in I_L which increases the return voltage. This causes a decrease of input current and a decrease of current supplied to the internal shunting resistance r_{22} in parallel with the load. The decrease of current through r_{22} must be greater than the decrease of current supplied in order that the load current increase at all. This is possible if the load voltage decreases considerably while the increase of load current is very slight. This very steep volt-ampere characteristic makes the transistor appear to the load as very nearly a constant current source, which is to say that the output impedance is extremely high. This is the desired characteristic for an electronic voltmeter since the indicating meter is current driven. The derivation of an equation for output resistance is a problem for the student.

AC SERIES NEGATIVE VOLTAGE FEEDBACK

The general voltage feedback circuit is that of figure 19. Figure 20 is for determining a Thevenin equivalent of the feedback circuit in series with R_L , in order to find the apparent input resistance R_L' . The Thevenin

$$E_{Fo} = \frac{R_F \cdot A_i \cdot I_L \cdot R_L}{R_D + R_L + R_F} \quad (30)$$

and internal resistance is

$$\frac{R_F \cdot (R_D + R_L)}{R_D + R_L + R_F} \quad (31)$$

Figure 21 shows that the input resistance is

$$R_L' = R_L + \frac{R_F \cdot R_L \cdot A_i + R_F (R_D + R_L)}{R_D + R_L + R_F} \quad (32)$$

This may be put in the form

$$R_L' = R_L \left(1 + \frac{R_F}{R_D + R_F} \cdot A_V \right) + \frac{R_F (R_D + R_L)}{R_D + R_L + R_F} \quad (33)$$

where $\frac{R_F}{R_D + R_F} = F_O$ is the open circuit feedback fraction, and the

last term is the resistance looking into the feedback circuit. And like equation 29, the voltage gain with feedback is

$$A_V' = \frac{A_V}{1 + F_O A_V + \frac{R_F}{R_L} \cdot \frac{R_D + R_L}{R_D + R_L + R_F}} \quad (34)$$

Output impedance may be obtained by dividing the open circuit output voltage, with R_L infinite in figure 19, by the short circuit current. It is noted that when R_L is zero there is no feedback. The short circuit current may be calculated after calculation of the input current for an input resistance of r_i in series with the feedback resistor R_F shunted by R_D . For the open circuit output voltage, R_L' may be obtained from equation 33 with $R_L \neq r_{i1}$.

Input current I_1 may then be calculated. The open circuit output voltage is

$$E_{oc}' = I_1 R_L \cdot A_V \quad (35)$$

R_1 and A_v are to be obtained from equations 49 and 50, p. 16 of "Transistor Parameters".

$$R_2' = \frac{E_{oc}'}{I_{sc}} \quad (36)$$

It is to be observed that the driving source impedance enters into the determination of the output impedance. If the source impedance is infinite, I_1 is constant, and the output impedance is r_{22} paralleled by R_D . But if the source impedance is low, then I_1 is large for the short circuit test, and small for the open circuit test. This makes for a much smaller output impedance. This result is also seen in equation 5.

AC SHUNT NEGATIVE VOLTAGE FEEDBACK

The self bias circuit of figure 8, page 16 of "Bias" has this kind of feedback, as was mentioned on page 5 of that chapter. A general circuit diagram is shown in figure 22. It is observed that the output voltage must be opposite in phase to the input, in order that the feedback path divert AC current away from the transistor. Figure 23 replaces the output by a voltage $A_v \cdot E_1'$ in order to find the input resistance.

$$I_{in} = \frac{E_1'}{R_1} + \frac{E_1'(A_v + 1)}{R_F} \quad (37)$$

$$R_1' = \frac{E_1'}{I_{in}} = \frac{R_1 R_F}{R_F + R_1(A_v + 1)} \quad (38)$$

This reduced value of input resistance causes a reduction in voltage gain of the preceding stage, and some change of its current gain.

There is no effect on the voltage gain of the stage around which feedback is placed, except as R_F reduces the loading resistance. There is also no effect on the current gain with respect to the actual input current I_L . In the case of a transducer driving the transistor, figure 24 gives the reduction of input voltage as

$$\frac{E_L'}{E_L} = \frac{1 + \frac{R_S}{R_L}}{1 + \frac{R_S}{R_L'}} \quad (39)$$

Output resistance is derived by decreasing R_L to cause an increase in I_L and a decrease in V_L in figure 22. Figure 25 shows the changes caused by the decrease of R_L .

$$\Delta I_F = \frac{\Delta V_L}{R_F + R_{1S}} \quad (40)$$

where R_{1S} is the symbol for the parallel resistance of R_L and R_S .

$$\Delta I_L = \frac{R_S \Delta I_F}{R_L + R_S} = \frac{R_S \Delta V_L}{(R_L + R_S) \cdot (R_F + R_{1S})} \quad (41)$$

$$\Delta I_L = A_i \cdot \Delta I_L + \Delta I_F \quad (42)$$

Substitution of 40 and 41 yields

$$R_2' = \frac{R_F + R_{1S}}{\frac{R_S A_i}{R_L + R_S} + 1} \quad (43)$$

Negative voltage feedback results in a reduced value of output resistance both for shunt and series feedback.

AC SHUNT NEGATIVE CURRENT FEEDBACK

A general circuit diagram is figure 26. Current gain, including feedback is

$$A_i' = \frac{I_L}{I_{in}} = \frac{I_L}{I_L + F \cdot I_L} = \frac{A_i}{1 + F \cdot A_i} \quad (44)$$

Compare this with equation 23. Analysis of the circuit gives

$$\frac{I_F}{I_L} = F = \frac{R_F + \frac{R_L}{A_i}}{R_D + R_F} \quad (45)$$

To obtain the input resistance

$$I_{in} = I_L + I_F = I_L (1 + F \cdot A_i) \quad (46)$$

$$R_1' = \frac{R_L \cdot I_L}{I_{in}} = \frac{R_L}{1 + F \cdot A_i} \quad (47)$$

The discussion between equations 38 and 39 applies here also.

Output resistance is derived by decreasing R_L , and then calculating the ratio of the decrease of load voltage to the increase of load current. Figure 27 shows the changes.

$$\Delta I_F = \frac{\Delta I_L \cdot R_F}{R_D + R_F + R_{1s}} = k_1 \Delta I_L \quad (48)$$

$$\Delta I_L = \Delta I_F \cdot \frac{R_s}{R_s + R_1} = k_2 \Delta I_F = K \Delta I_L \quad (49)$$

The equivalent current generator of the transistor is indicated by $\beta \Delta I_L$ in figure 27, where the meaning of β is here the short circuit current ratio of the amplifier with respect to I_L .

The output voltage decrease is

$$\Delta V_L = \Delta I_L \cdot R_F' \quad (50)$$

where

$$R_F' = R_F \cdot \frac{(R_D + R_{1s})}{R_D + R_F + R_{1s}} \quad (51)$$

Summing currents at point O gives

$$\Delta I_2 = \frac{\Delta V_L - \Delta I_L \cdot R_F'}{R_2} = \Delta I_L + \beta K \Delta I_L \quad (52)$$

Output resistance is

$$R_2' = \frac{\Delta V_L}{\Delta I_L} = R_2 (\beta \cdot K + 1) + R_F' \quad (53)$$

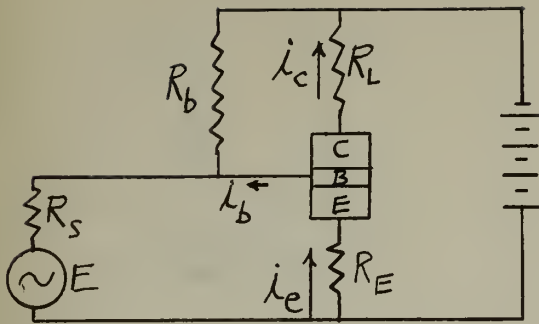


Figure 1
Emitter Degeneration

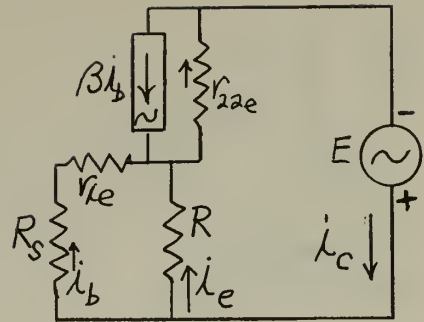


Figure 5
Output Resistance
AC Equivalent Circuit

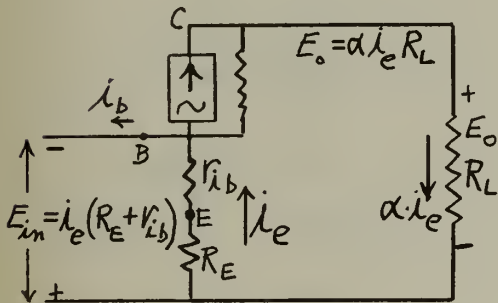


Figure 2
AC Equivalent Circuit

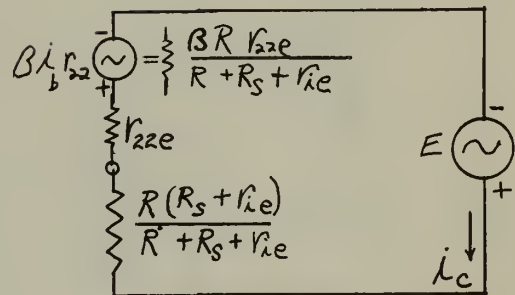


Figure 6
Output Resistance

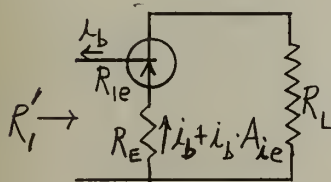


Figure 3
Input Resistance

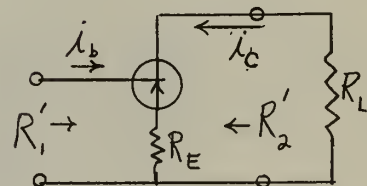


Figure 7
Emitter Degeneration

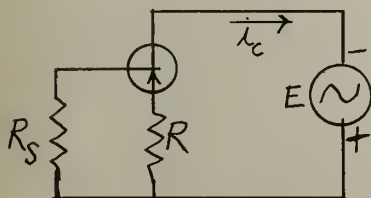


Figure 4
Output Resistance

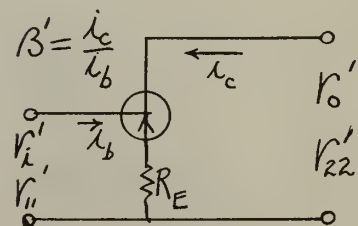


Figure 8
Combination Parameters

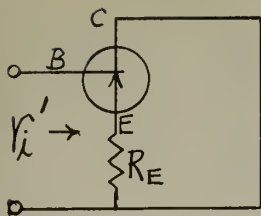


Figure 9
Input Resistance

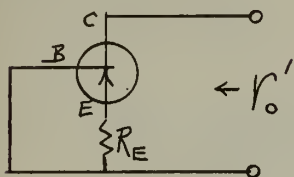


Figure 10
Output Resistance

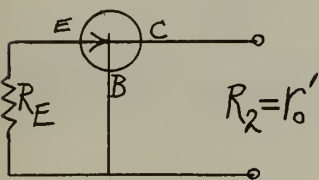


Figure 11
Output Resistance

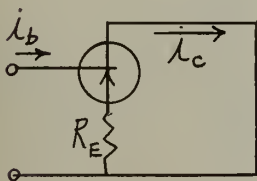


Figure 12
 β' Measurement

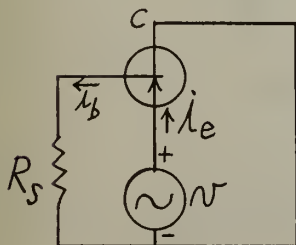


Figure 13
Output Resistance

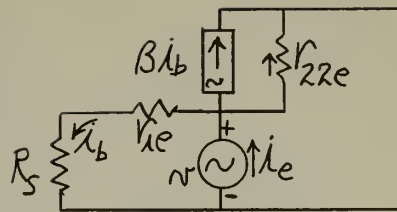


Figure 14
Output Resistance

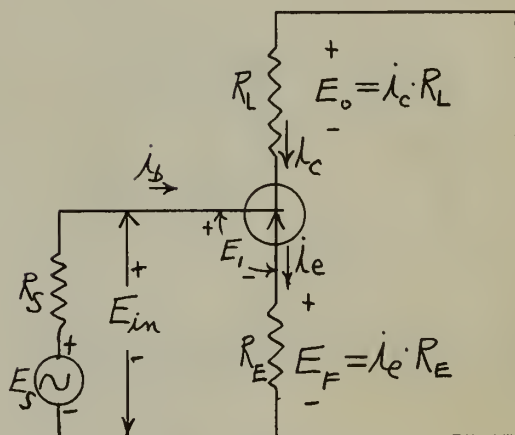


Figure 15
AC Series Negative Current
Feedback - Emitter Degeneration

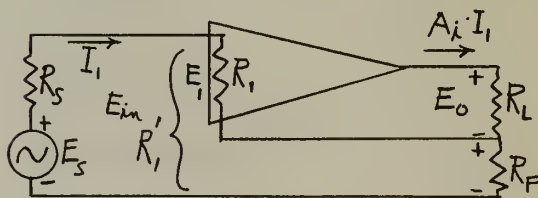


Figure 16
AC Series Negative
Current Feedback

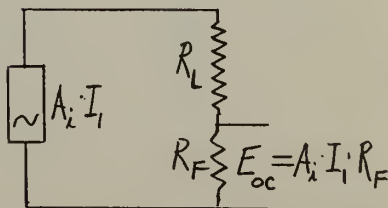


Figure 17a
Thevenin Equivalents of the
Feedback Circuit



Figure 17b

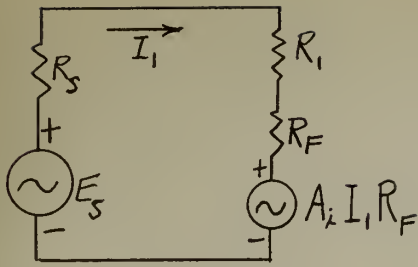


Figure 18
Equivalent Input Circuit

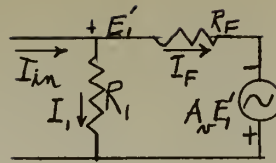


Figure 23
Equivalent Input Circuit of Figure 22

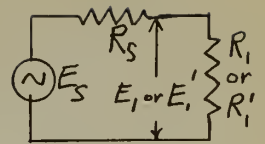


Figure 24
Input Voltage Affected by Feedback

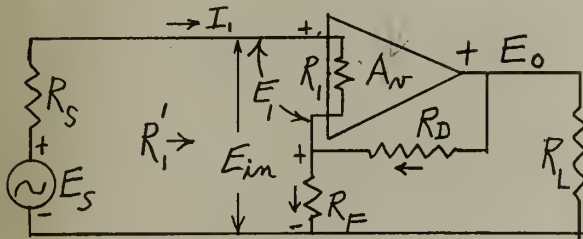


Figure 19
AC Series Negative Voltage Feedback

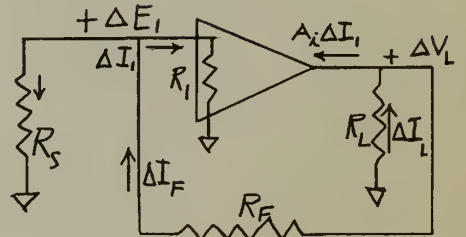


Figure 25
Output Resistance Determination by Reduction of R_L

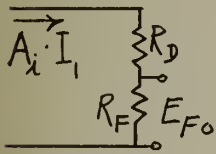


Fig. 20
Thevenin Evaluation of Feedback Circuit of Fig. 19

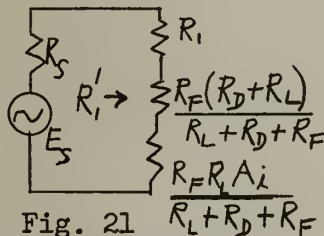


Fig. 21
Equivalent Input Circuit of Fig. 19

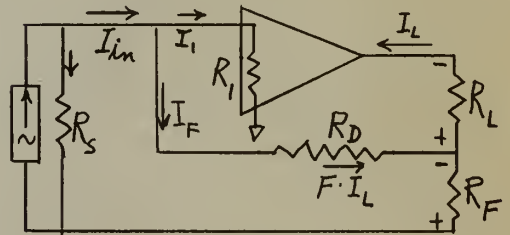


Figure 26
AC Shunt Negative Current Feedback

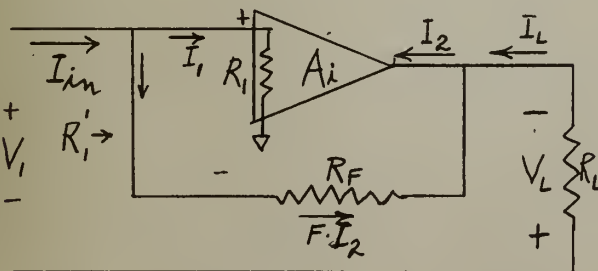


Figure 22
AC Shunt Negative Voltage Feedback

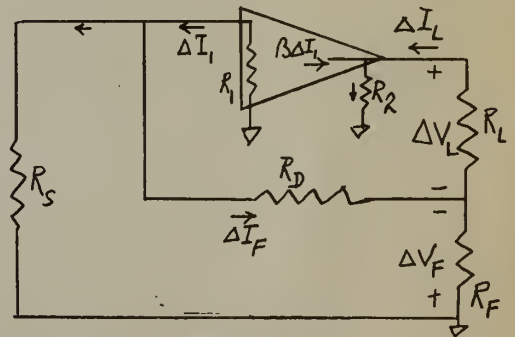


Figure 27
Output Resistance Determination by Reduction of R_L

TA7 37014
.U6 Bauer
no.18 Feedback in transistor
amplifiers.

AP 10 64
27 JAN 66
31 OCT 66
2 JUL 70

120010UP
14819
14951
18776

TA7 37014
.U6 Bauer
no.18 Feedback in transistor
amplifiers.

genTA 7.U6 no.18

Feedback in transistor amplifiers.



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